Spatial Disorientation

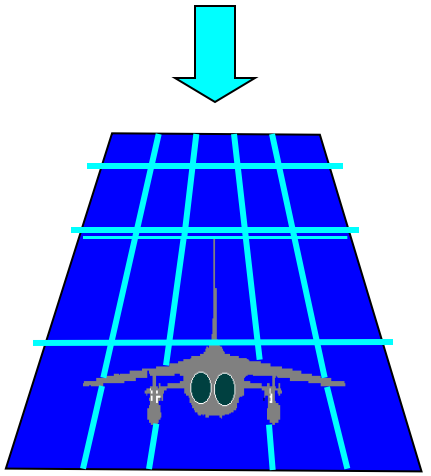
16.400/16.453

Human Factors Engineering

Prof. L. Young Sept. 2011

SPATIAL DISORIENTATION IN FLIGHT
Formal Definition

"[A failure] to sense correctly the position, motion or attitude of his aircraft or of himself [herself] within the fixed coordinate system provided by the surface of the earth and the gravitational vertical.



In addition, errors in perception by the aviator of his position, motion or attitude with respect to his aircraft, or of his own aircraft relative to other aircraft, may also be embraced within a broader definition of spatial disorientation in flight. ***-- Alan Benson (1978)***

SPATIAL DISORIENTATION IN FLIGHT
Spatial Disorientation Types

TYPE I -- *Unrecognized*

- **Pilot Does Not Consciously Perceive Any Manifestation of Spatial Disorientation**
- **Most Often Occurs When Pilot Breaks Instrument Cross-Check**
- **Most Likely to Lead to Controlled Flight Into Terrain**

SPATIAL DISORIENTATION IN FLIGHT
Spatial Disorientation Types

TYPE II -- *Recognized*

- **Pilot Consciously Perceives A Manifestation of Spatial Disorientation but May Not Attribute It to SD Itself**
- **Conflict between "Natural" and "Synthetic" SD Percepts May Occur**
- **Instrument Malfunction Is Often Suspected**

SPATIAL DISORIENTATION IN FLIGHT
Spatial Disorientation Types

TYPE III -- *Incapacitating*

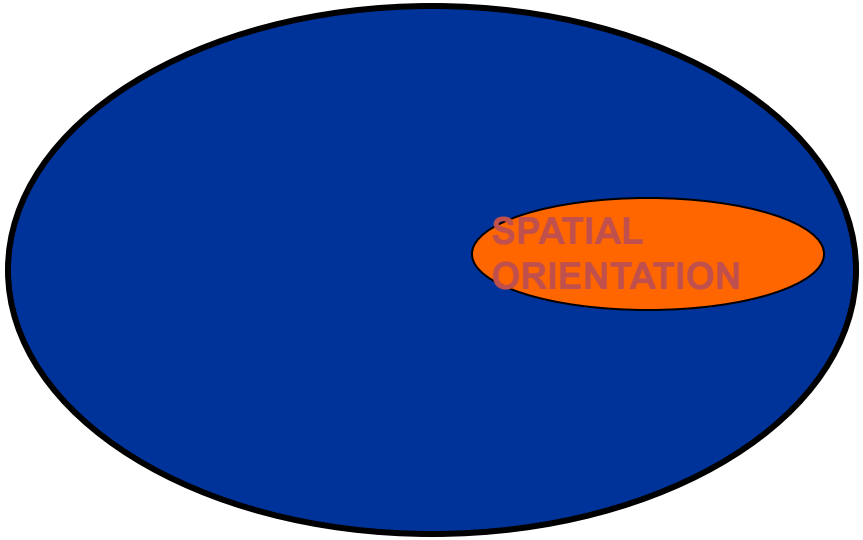
- Experienced by 10-15% of Aviators
- Vestibulo-Ocular Disorganization (i.e., uncontrollable nystagmus)
- Motor Conflict (e.g., “Giant Hand”)
- Temporal Distortion
- Dissociation (“Break-Off”)

SPATIAL DISORIENTATION IN FLIGHT
Predisposing Perceptual Factors

- SD Is More Likely to Occur at Night Or in Bad Weather
- Visual and Nonvisual Illusions Contribute Equally to SD
- Sparse Terrain Is More Challenging Than A Densely Vegetated One
- Loss Of Other Aspects Of Situation Awareness Can Lead to SD

SPATIAL DISORIENTATION IN FLIGHT
Loss of Situation Awareness and SD

- **Spatial Orientation is Part of Overall Situation Awareness**
- **SD Automatically Results in LSA**
- **Failure to Maintain Overall SA Can Lead to SD**
- **SA Is Especially Challenged in Poor Visual Conditions**



SA in Good Weather

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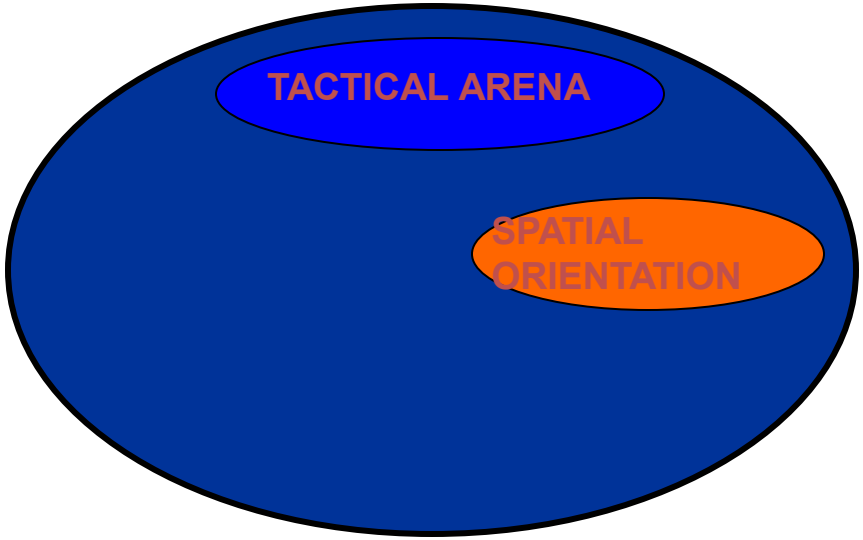

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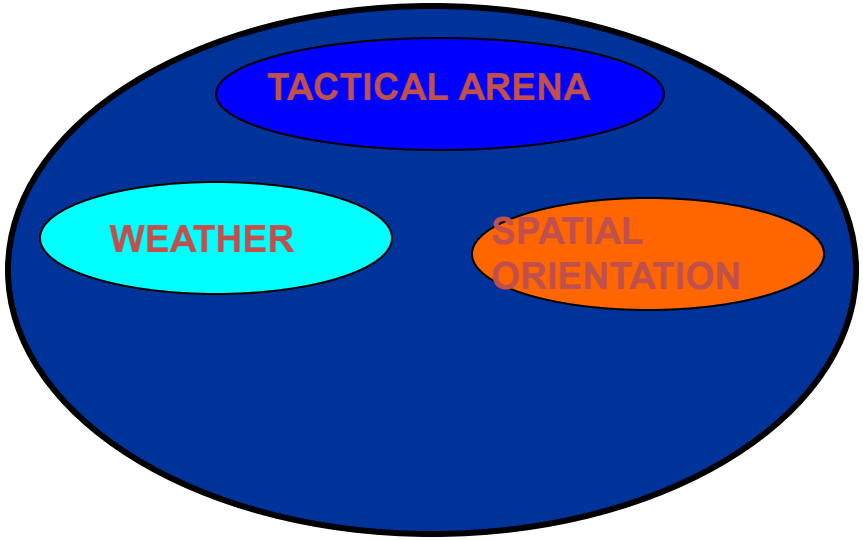

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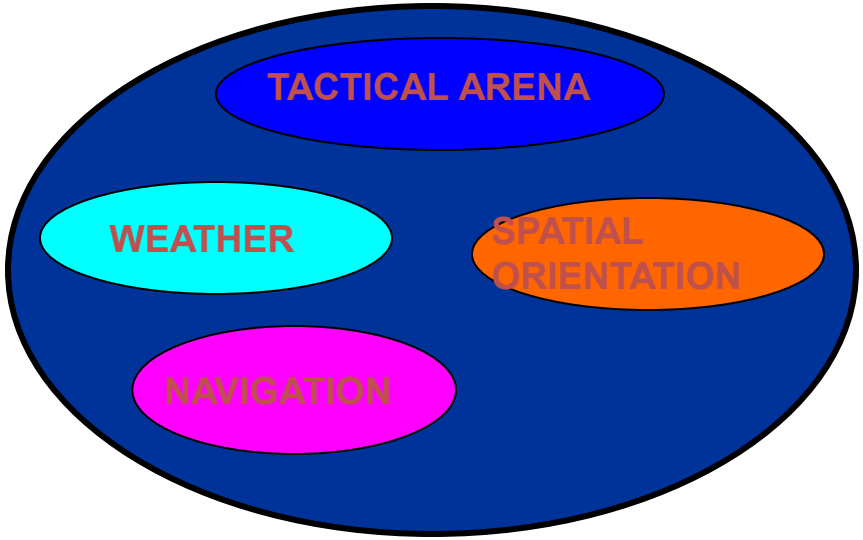

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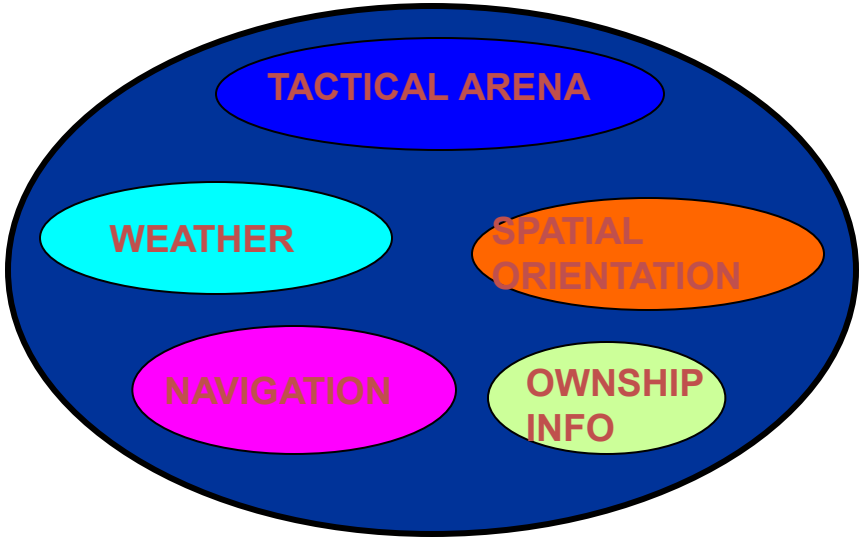

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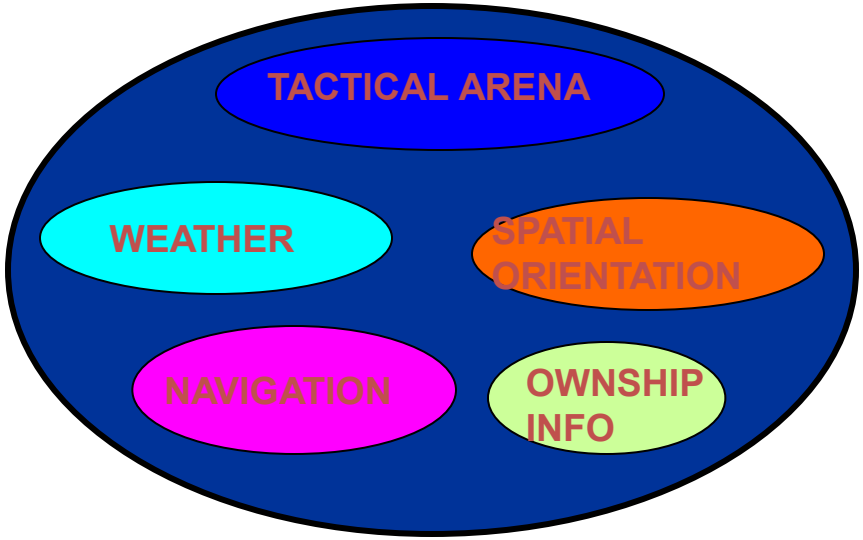

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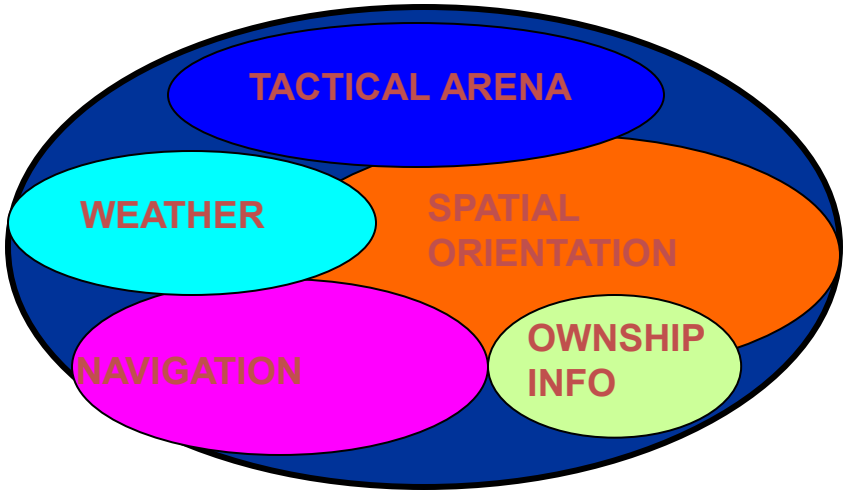


SA in Bad Weather

SPATIAL DISORIENTATION IN FLIGHT
Pilot-Specific Factors

- **Experience**
  - Number of hours (no linear relationship with age)
  - Instrument proficiency
  - Training experience
- **Type of Aircraft (100% SD in fighter pilots)**
- **Medical Conditions**
  - Alternobaric vertigo
  - Positional nystagmus

SPATIAL DISORIENTATION IN FLIGHT
USAF Mishap Statistics and Costs

1980s

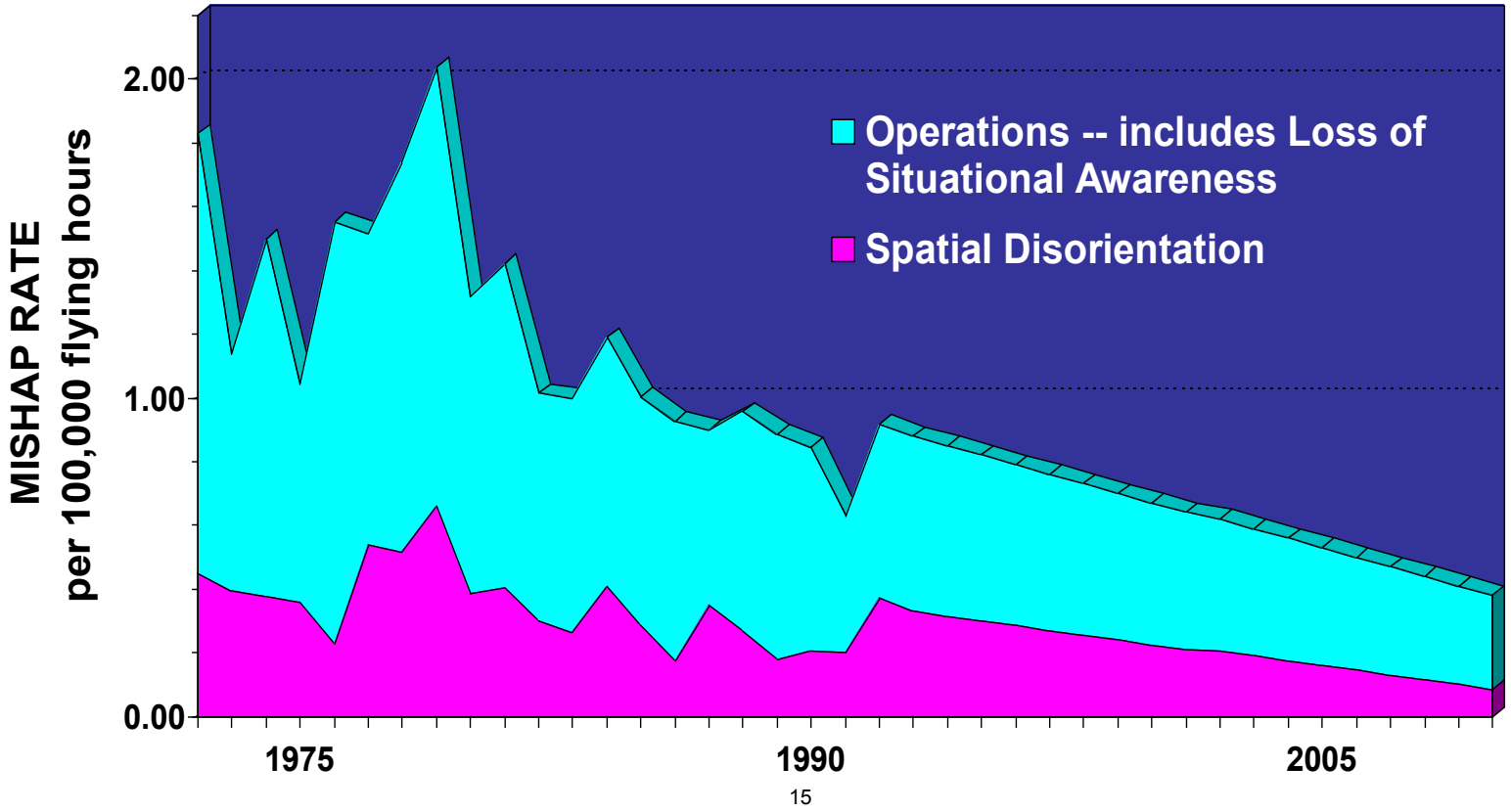
- **SD and/or LSA Account for 27 Mishaps Per Year**
  - **Approximately 43% of all USAF Class A mishaps**
  - **43 fatalities annually (85% of all operational-related)**
  - **8 SD mishaps annually ($100M per annum cost)**

1990s

- **SD and/or LSA Account for Over 15 Mishaps Per Year**
  - **Over 50% of all USAF Class A mishaps**
  - **5 SD mishaps annually ($80M per annum cost)**
  - **SD/LSA mishaps decreasing *in number***

SPATIAL DISORIENTATION IN FLIGHT
USAF Mishap Rates

SD Class A Mishap *Rate* is Largely Unchanged from 1970s!

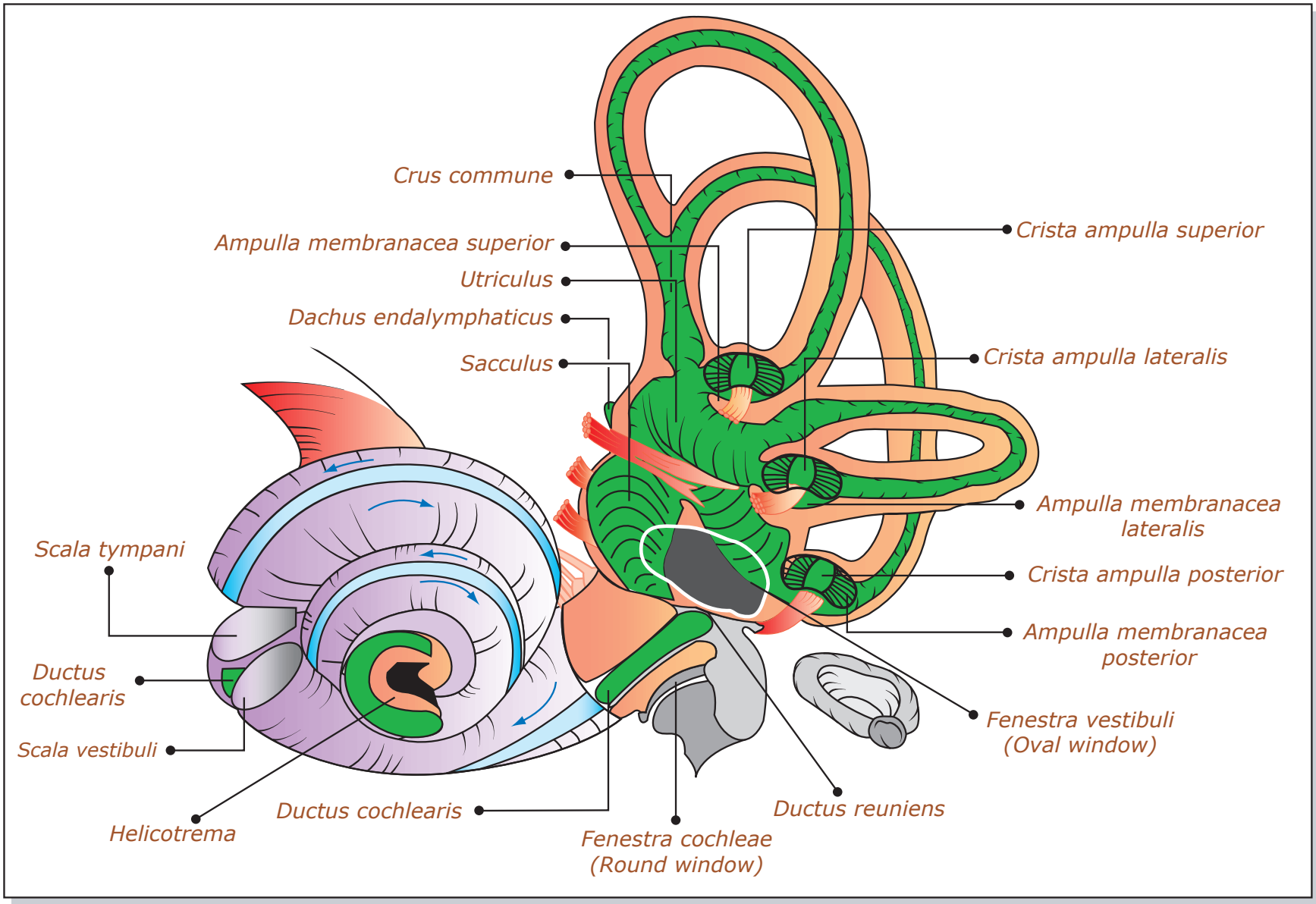


The Inner Ear and SD

Sensing Motion

We Don’t Fly by the Seat of Our Pants
(or do we?)

The Giant Hand



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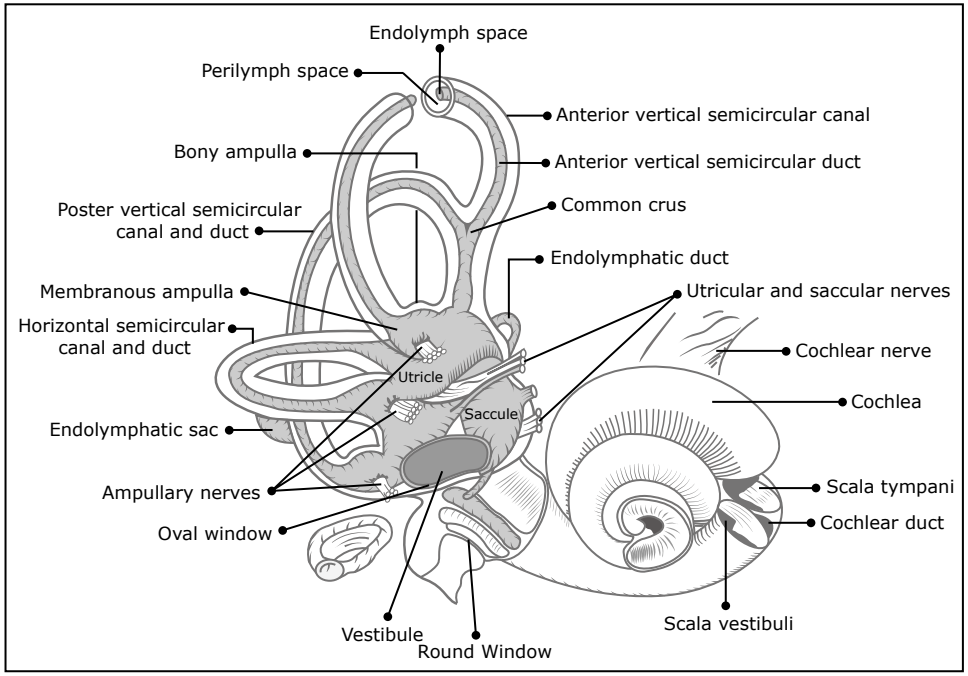
SPATIAL ORIENTATION IN FLIGHT
Vestibular Orientation Mechanisms

"The vestibular nerve occupies a special position among the senses. Its sensations do not form part of our conscious knowledge of the world…Whenever we perceive an object we have the basic knowledge about our body and about the attitude of our body…



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The vestibular apparatus with its influence on the muscle tone plays a part in every perception… Our impressions concerning our attitudes, the posture of our body, and the motility of the body… form the continuous background of our experiences. That this background is not in the full light of consciousness does not impair its importance." -- *Paul Schilder (1933)*

VESTIBULAR ORIENTATION
Cardinal Principle of Vestibular Function

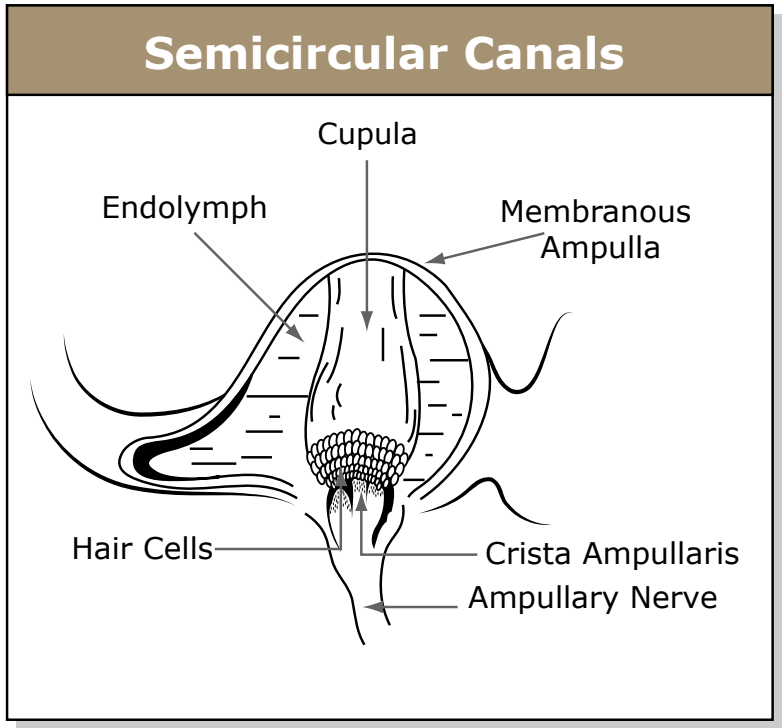
Semicircular Canals

- Designed to detect angular accelerations generated during terrestrial activity

Otolith Organs

- Designed to detect linear accelerations generated during terrestrial activity
- Signal head orientation relative to gravity/gravitoinertial force

VESTIBULAR ORIENTATION
Transduction in the Labyrinth



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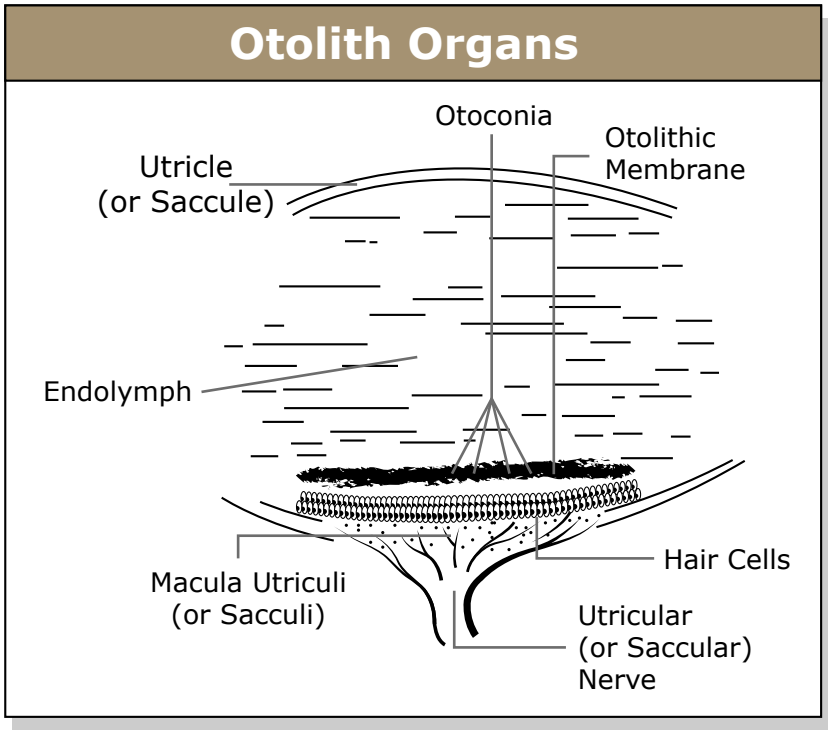

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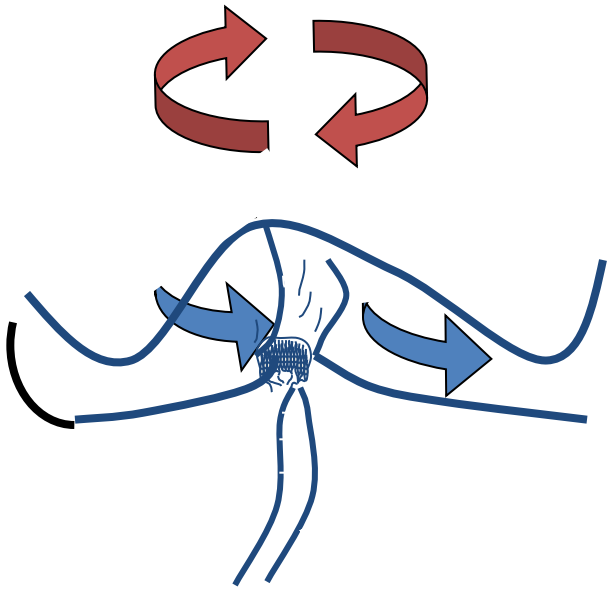
VESTIBULAR ORIENTATION
Semicircular Canal Function

Head acceleration



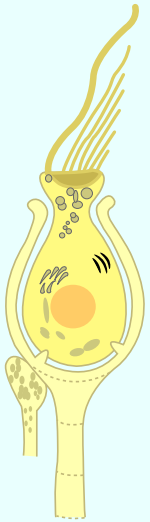
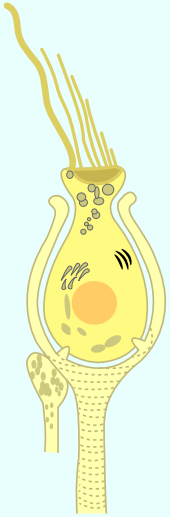
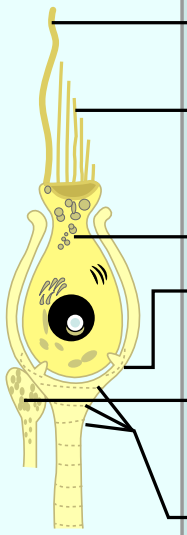
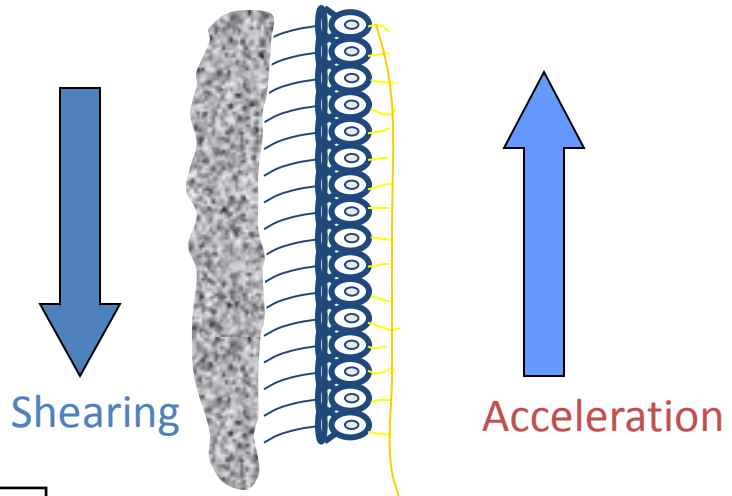
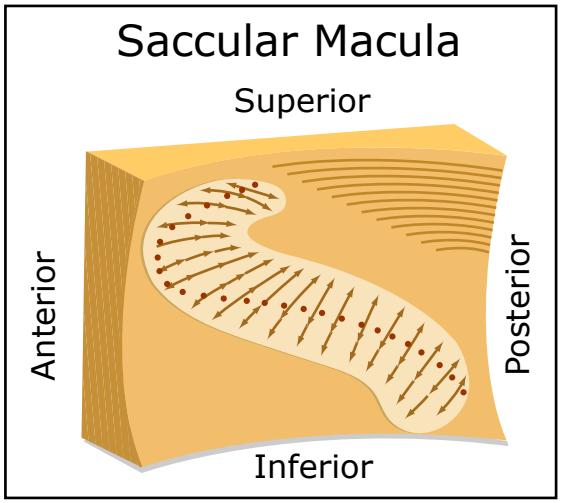
Away from Kinocilium	Toward Kinocilium	Neutral	Position of Cilia
			Kinocilium (1) Stereocilia (60-100) Hair cell Vestibular afferent nerve ending Vestibular efferent nerve ending Action potentials
Hyperpolarized	Depolarized	Normal	Polarization of hair cell
Lower	Higher	Resting	Frequency of action potentials

Image by MIT OpenCourseWare.

VESTIBULAR ORIENTATION
Functioning of the Otoliths





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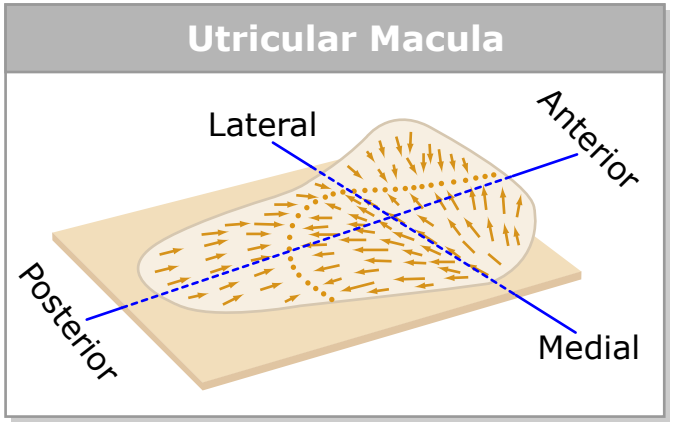

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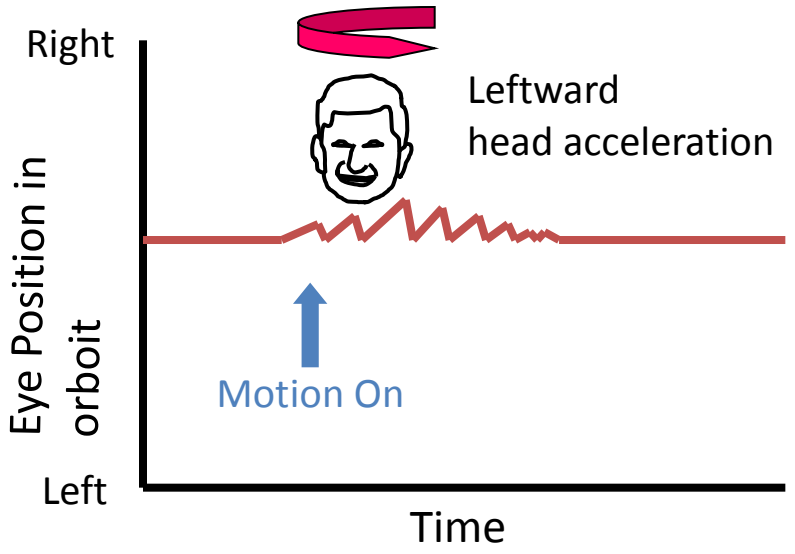
VESTIBULAR ORIENTATION
Vestibular-Ocular and -Cervical Reflexes

Vestibular Nystagmus

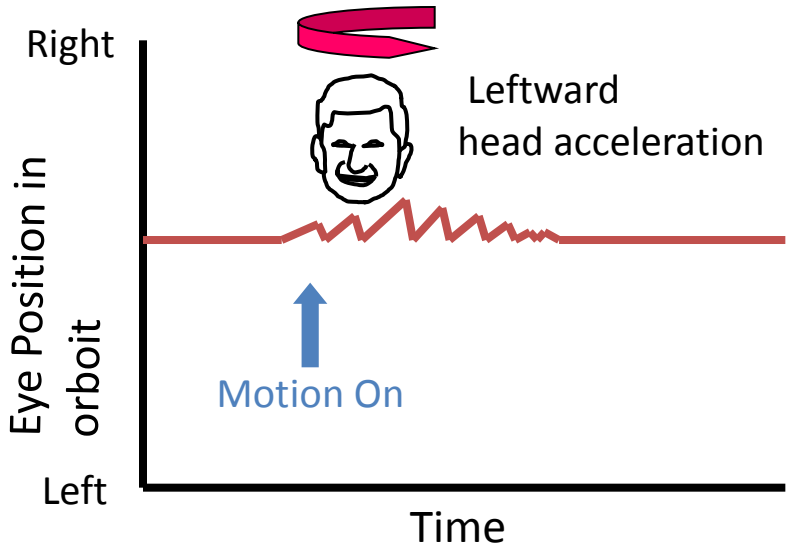
- Compensatory movement of eyes opposite to head motion (slow-phase)

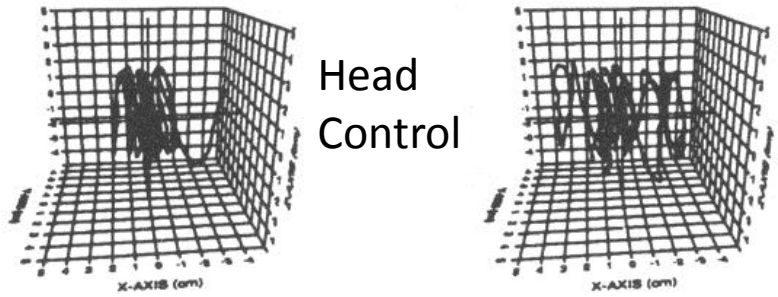


VESTIBULAR ORIENTATION
Vestibular-Ocular and -Cervical Reflexes

Vestibular Nystagmus

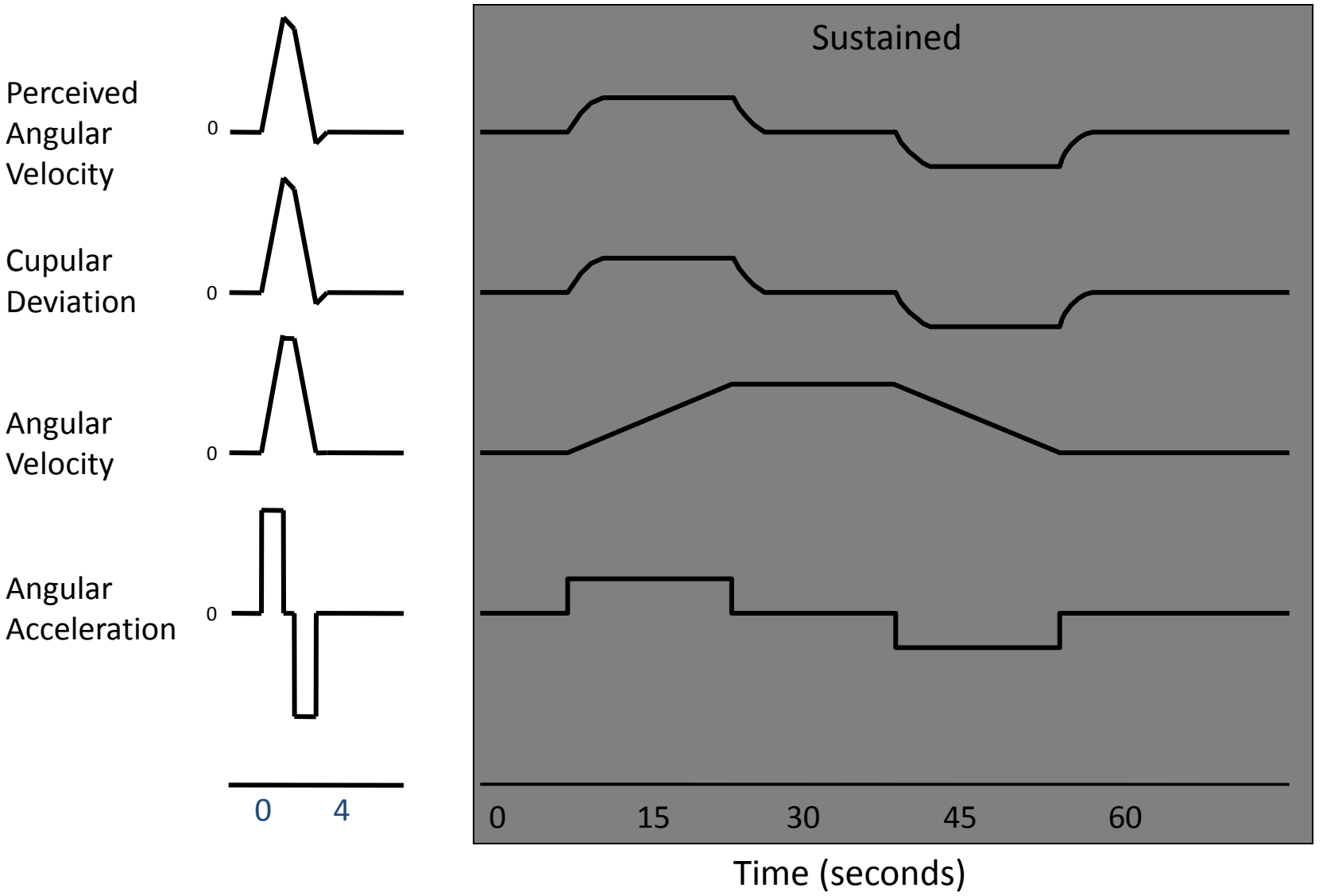
- Compensatory movement of eyes opposite to head motion (slow-phase)
- Designed to stabilize retinal inputs
- Can be driven by canals or otoliths
- Gain of nystagmus is highest in frequency range of natural head movements
- Nystagmus ceases in long-rotation turn; decays gradually thereafter
- Nystagmus, along with vestibular- cervical reflexes controlling the head, help provide a stabilized space while locomoting in the environment





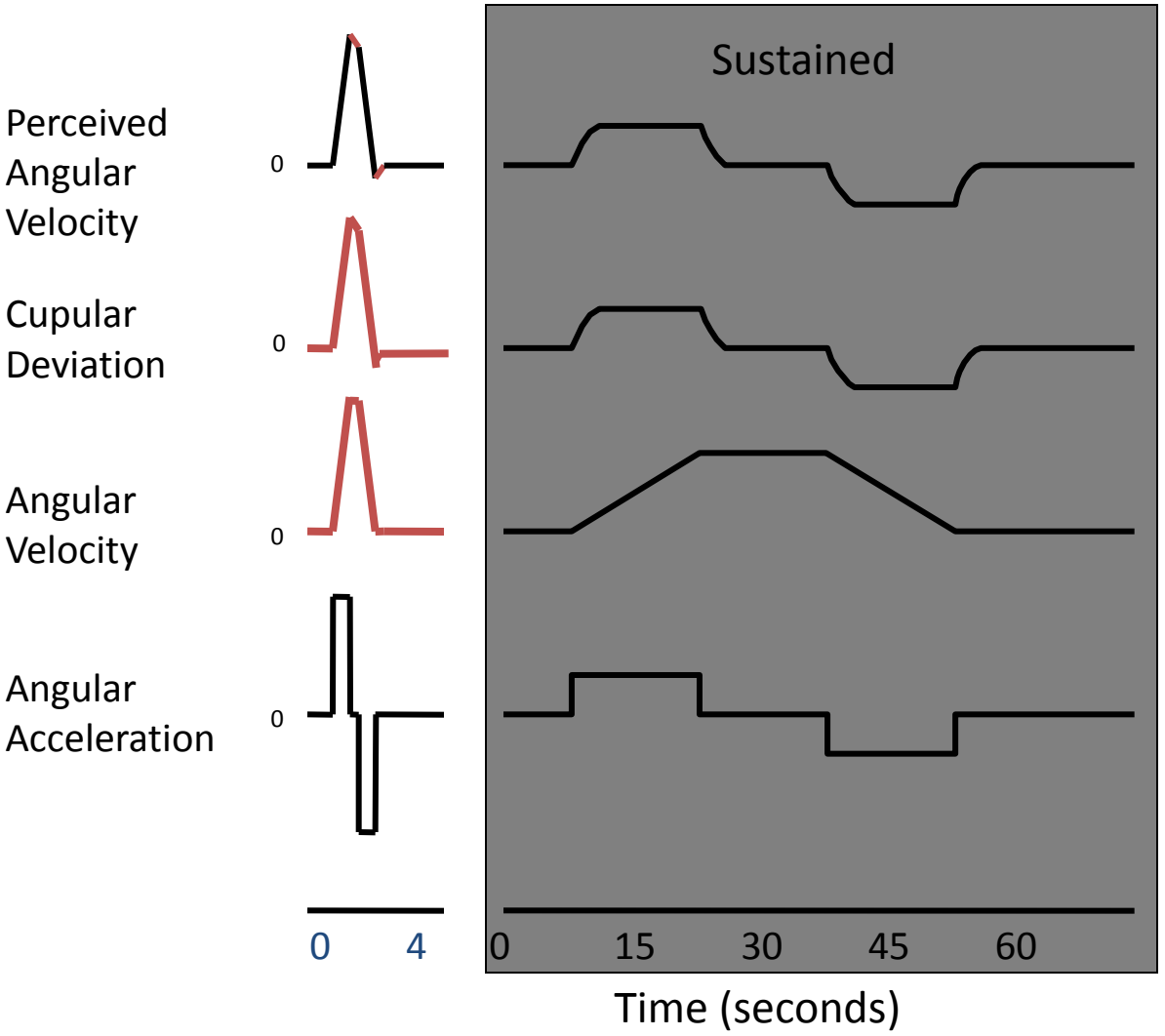
W/graviception *WO/graviception*

VESTIBULAR ORIENTATION
Canal Limits in Sustained Turns



VESTIBULAR ORIENTATION
Canal Limits in Sustained Turns

In brief turns, canals effectively integrate angular acceleration into velocity signal!



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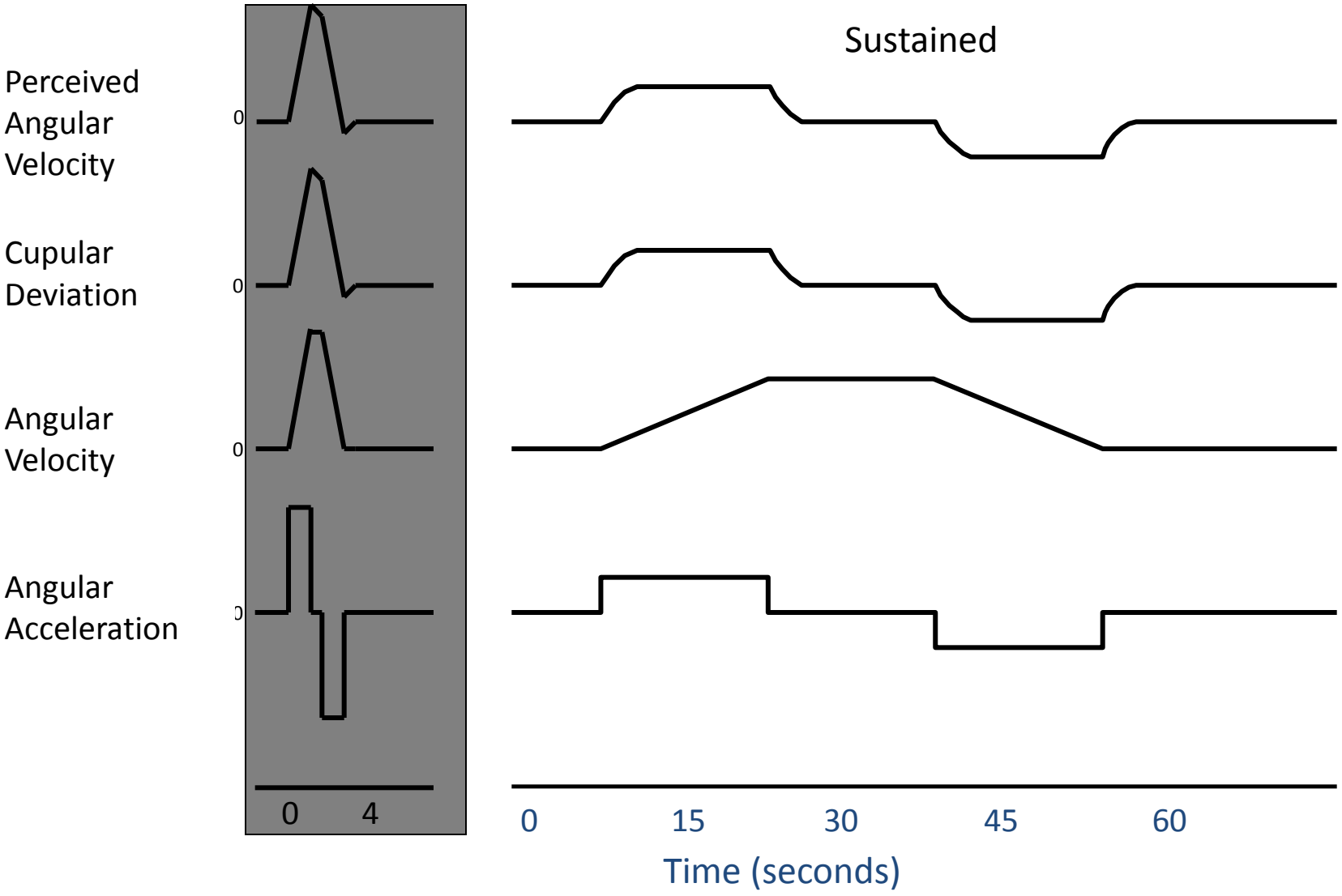
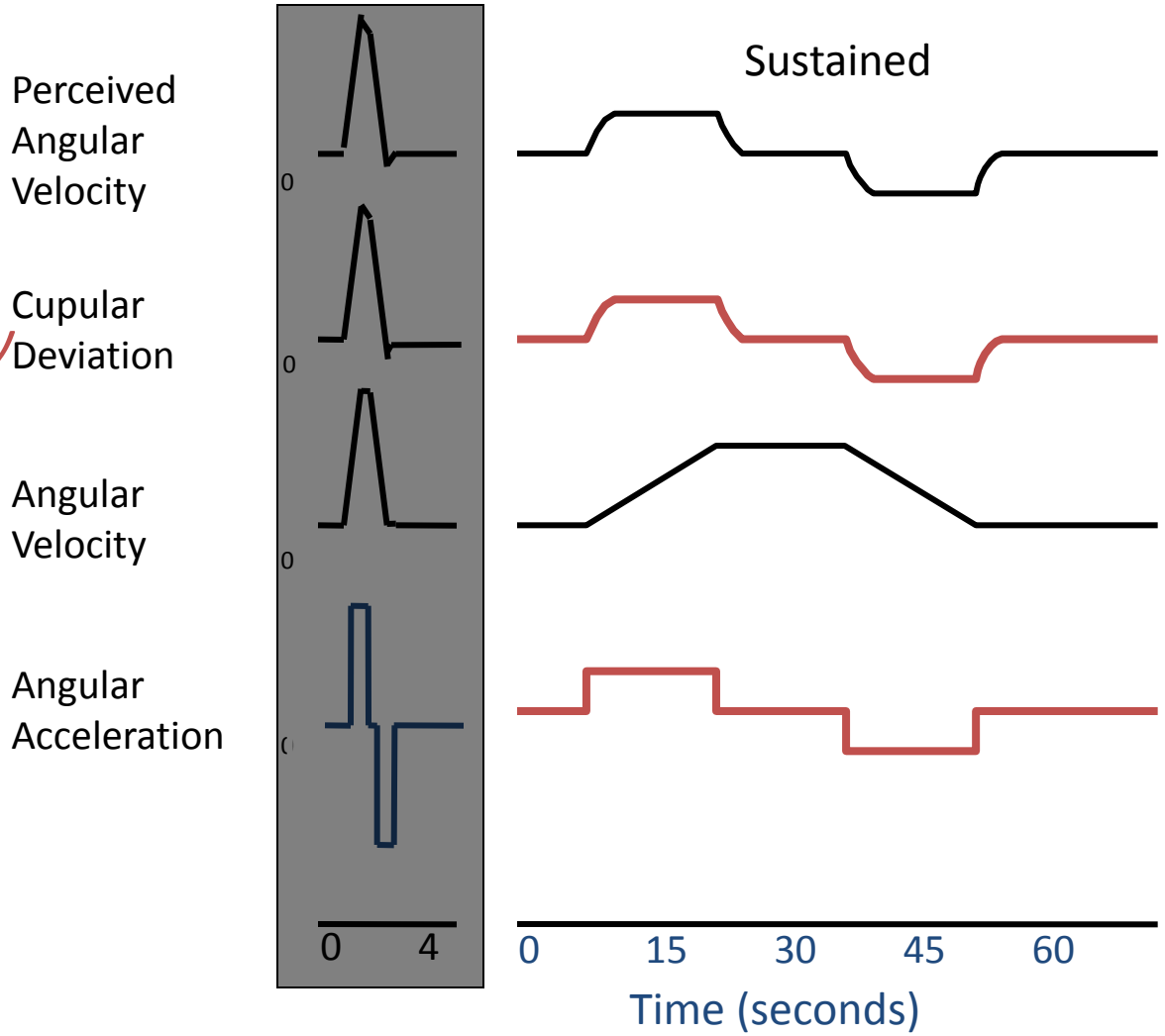


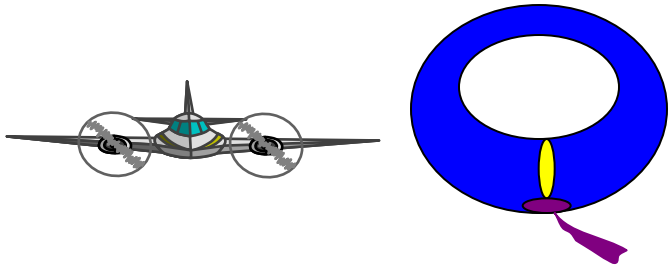
VESTIBULAR ORIENTATION
Canal Limits in Sustained Turns

In prolonged turns, canals only detect acceleration; velocity is consequently misperceived!

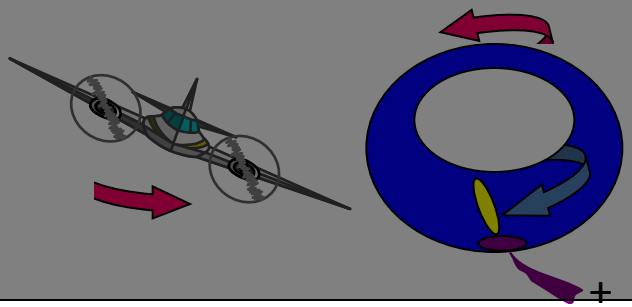


VESTIBULAR ORIENTATION
Canal "Percept" During Sustained Turning

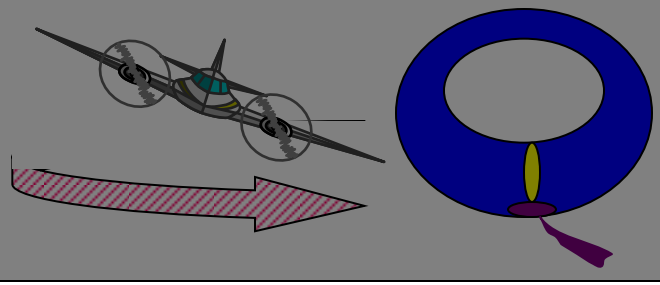
1. "*Straight-and- level" flight*: Cupula in neutral position



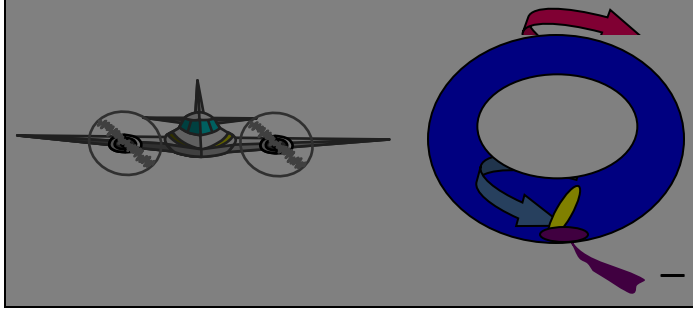
2. *Initial turn to left*: Cupula deviated by endolymph inertia; leftward acceleration detected



3. *Sustained turn to left*: Cupula returns to neutral position as endolymph "catches up"; no turning detected



4. *Return to "straight- and - level"* : Cupula deviated by endolymph momentum, gradually restored; rightward turn perceived



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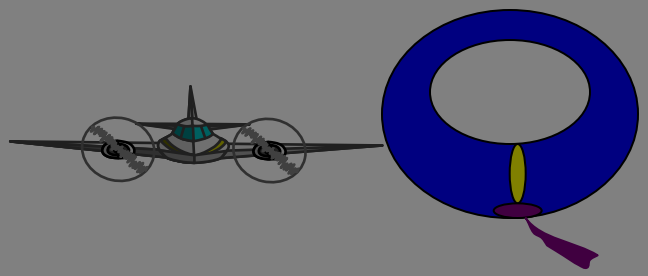

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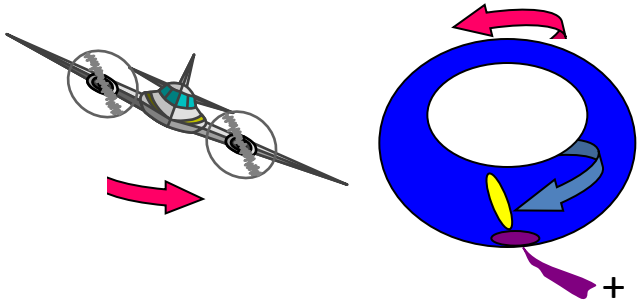

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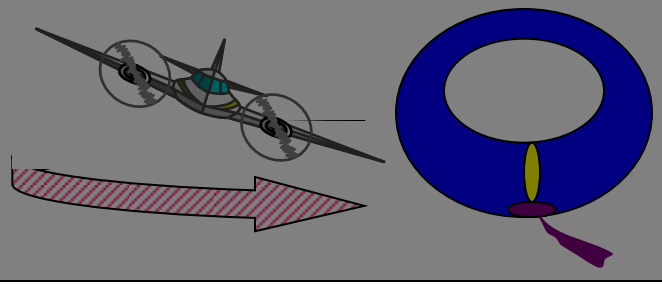

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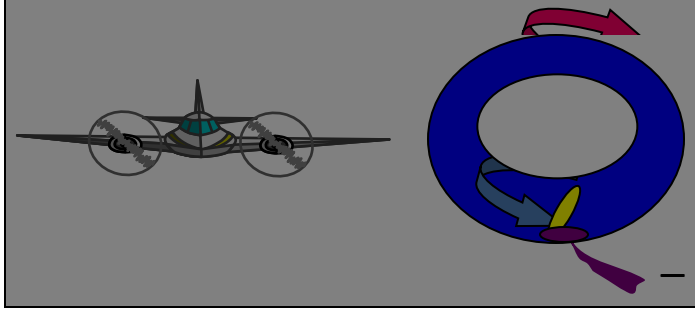

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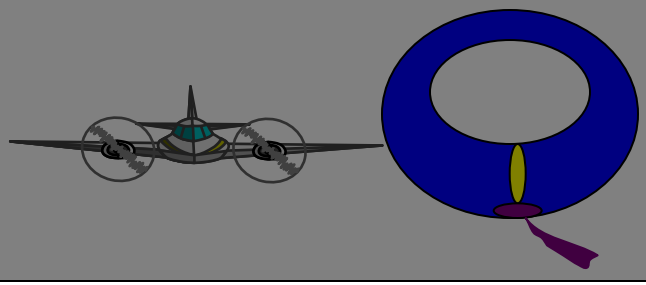

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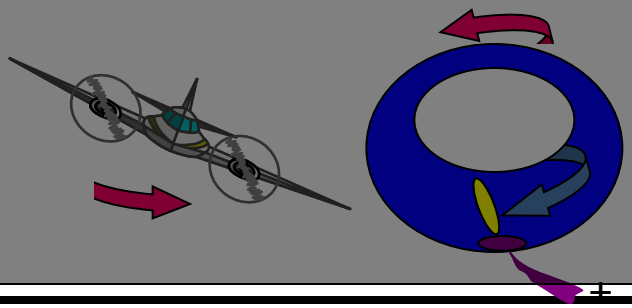

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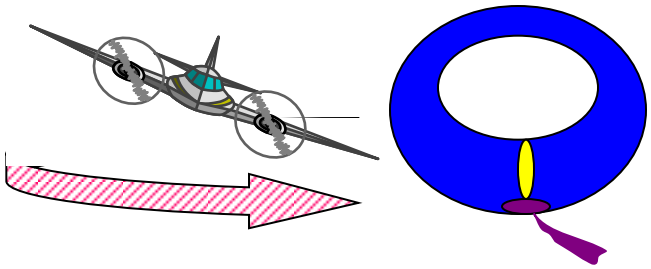

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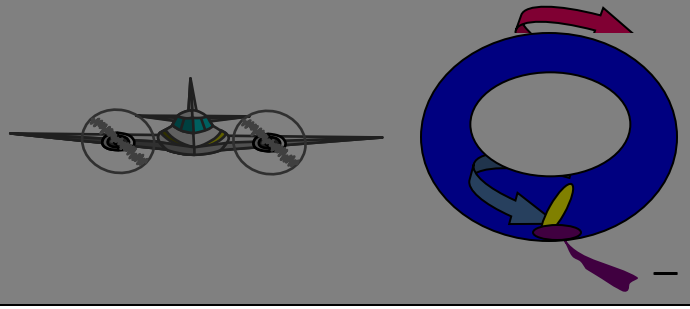

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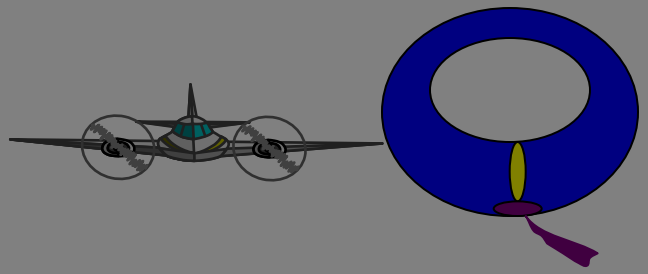

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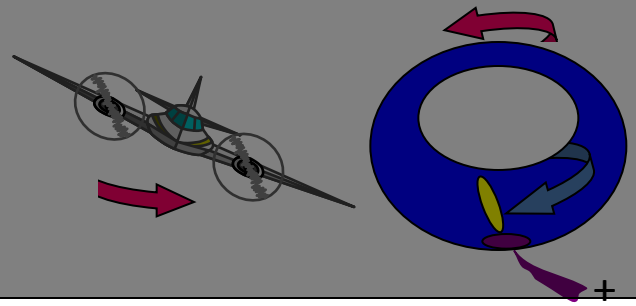
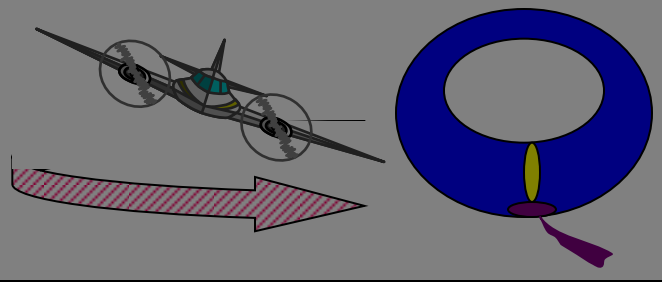
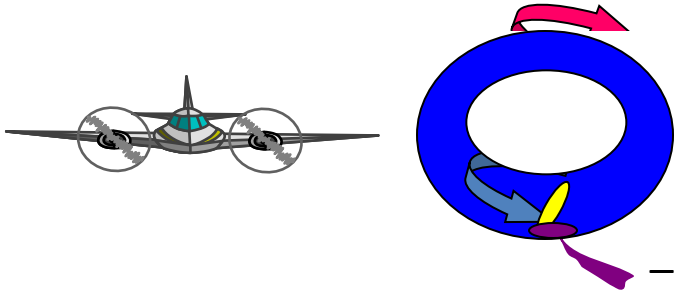


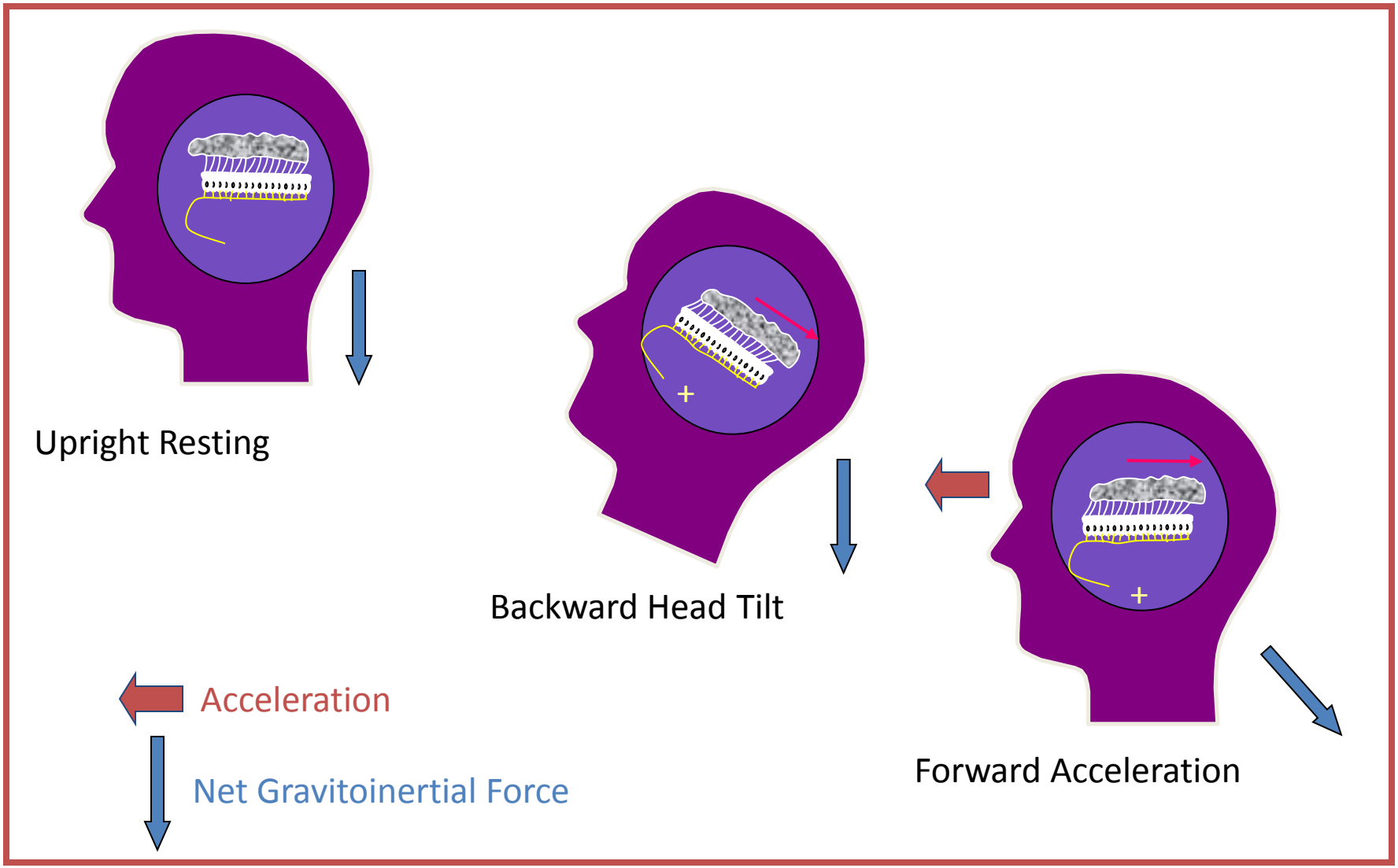
3. *Sustained turn to left*: Cupula returns to neutral position as endolymph "catches up"; no turning detected



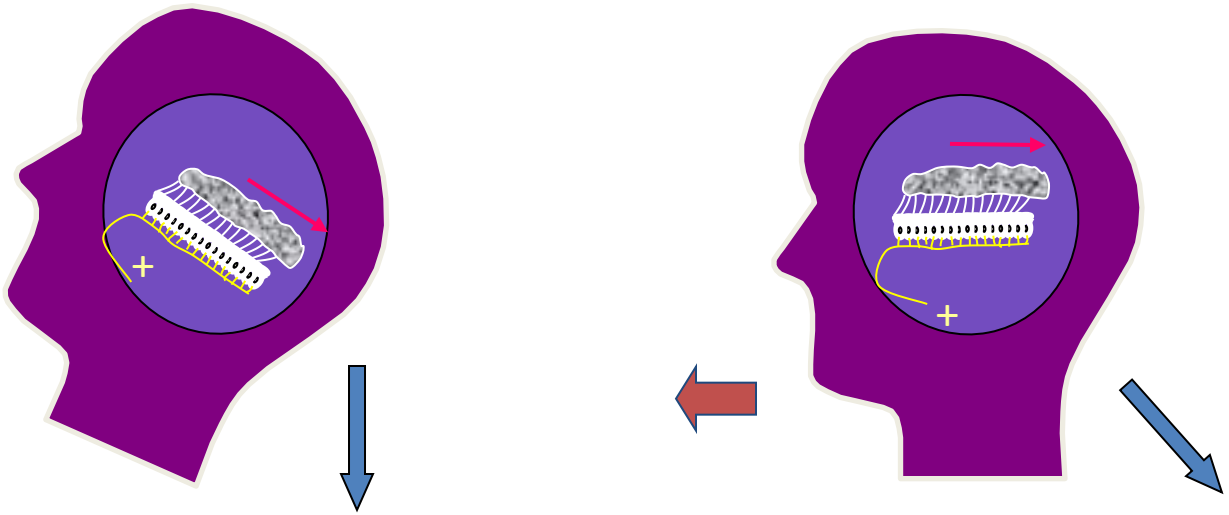
4. *Return to "straight- and - level"* : Cupula deviated by endolymph momentum, gradually restored; rightward turn perceived



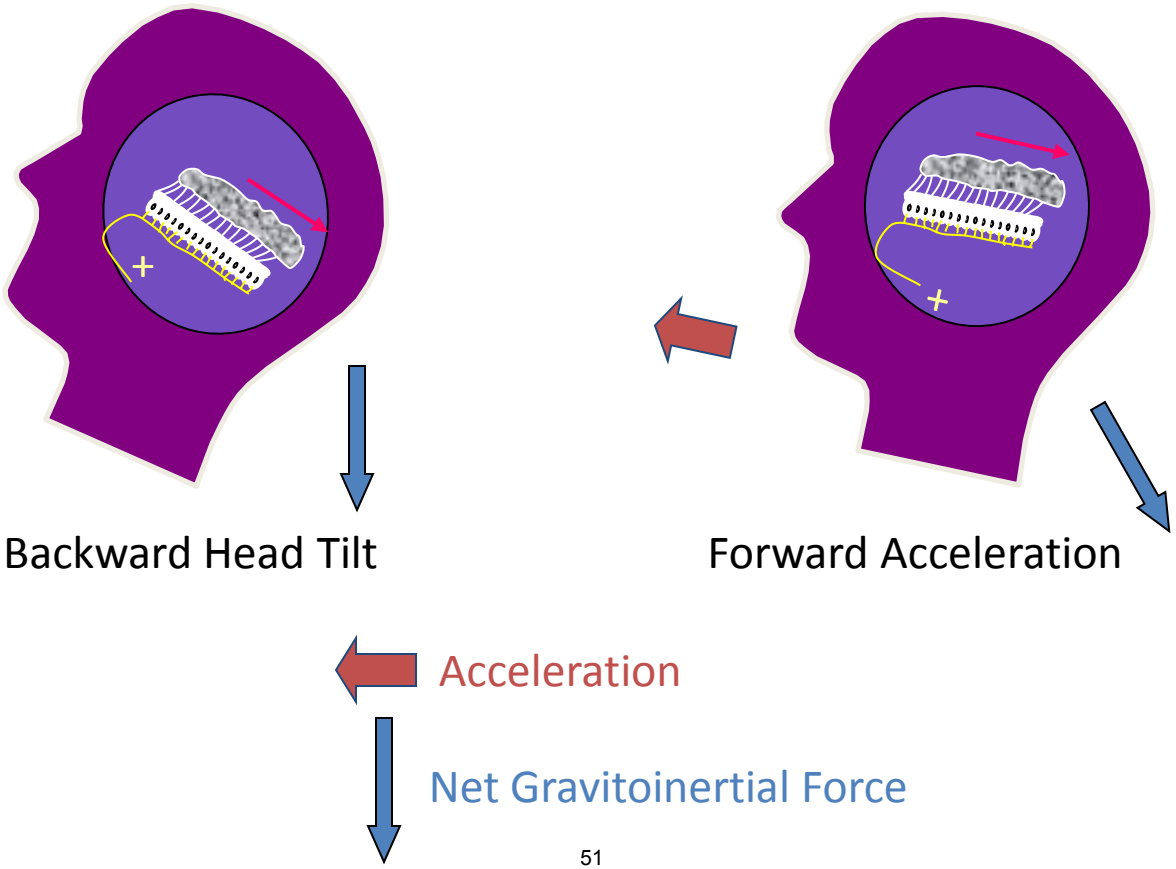
VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



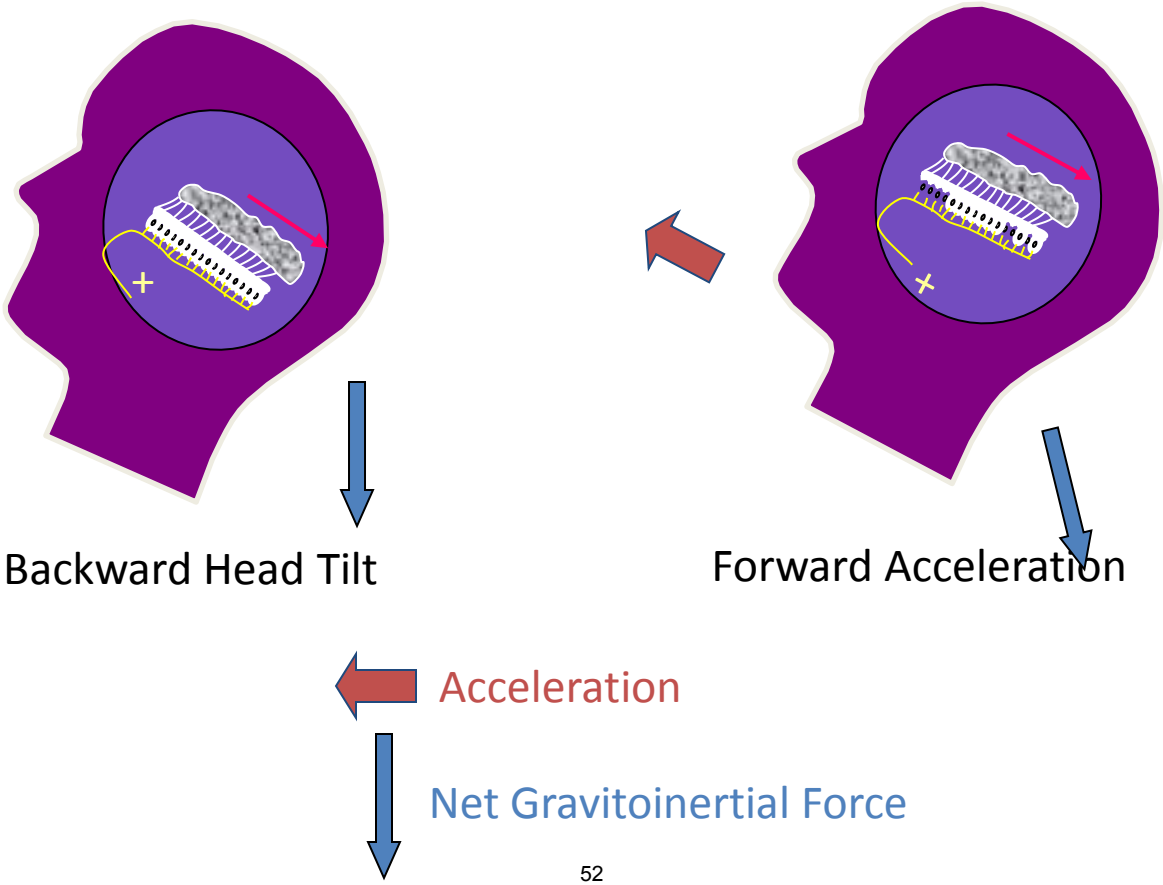
VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



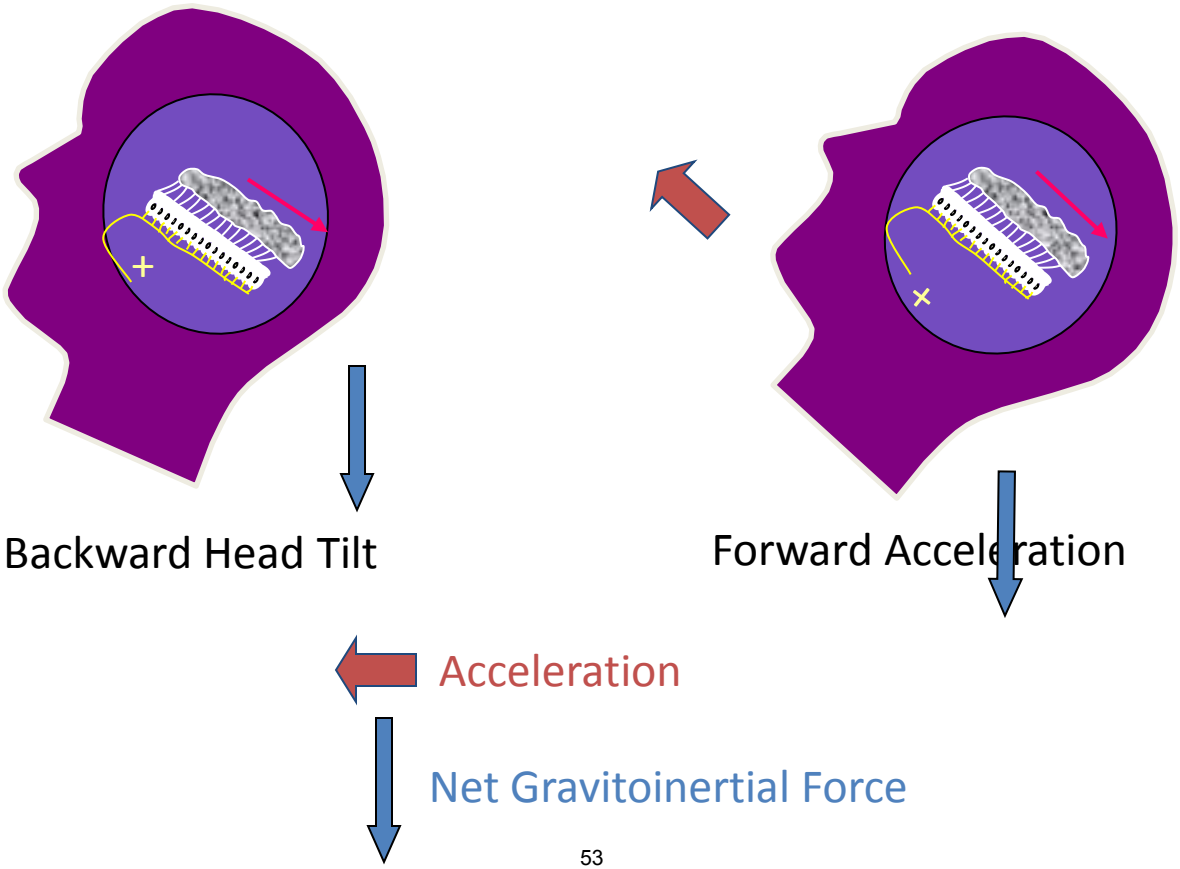
VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



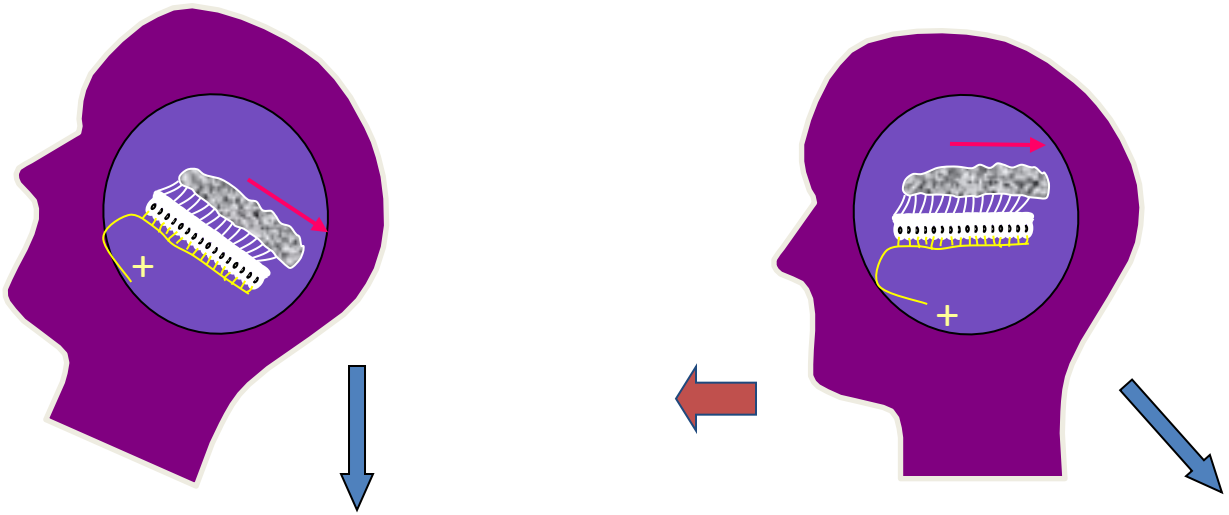
VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



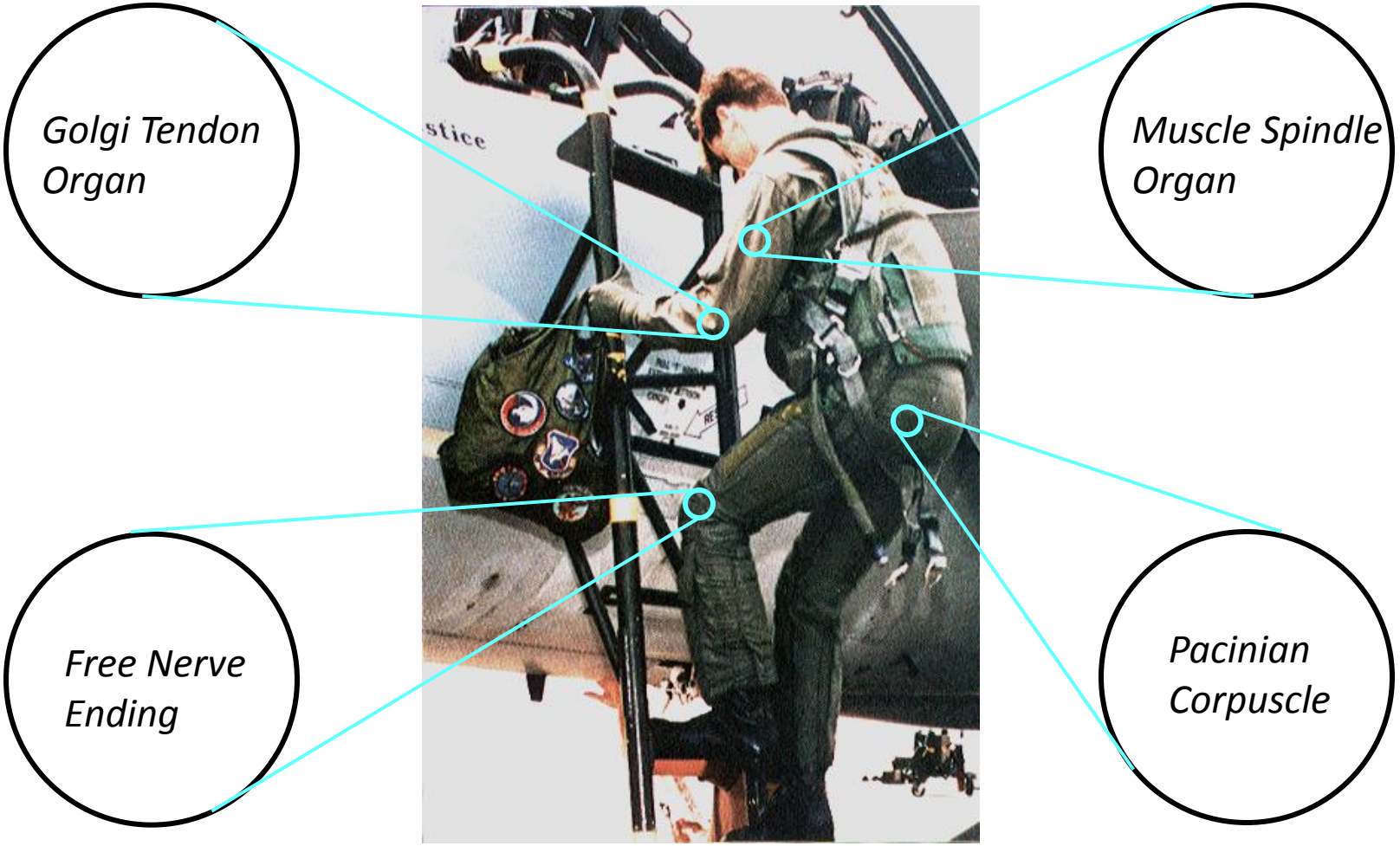
VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



VESTIBULAR ORIENTATION
Otolith Ambiguity In Sustained Acceleration



SPATIAL ORIENTATION IN FLIGHT
Somatosensory Mechansims



SPATIAL ORIENTATION IN FLIGHT

Motor Systems

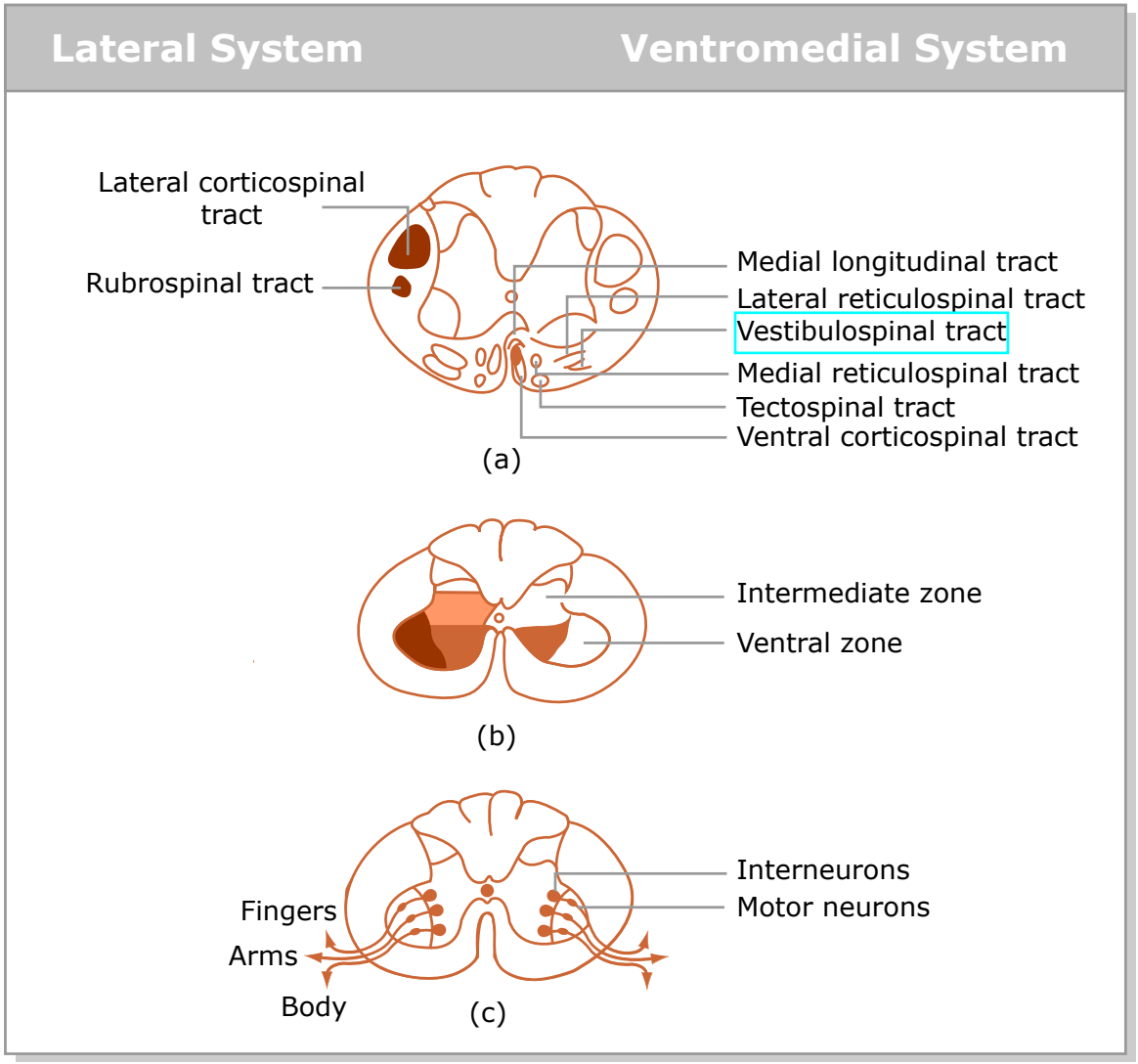
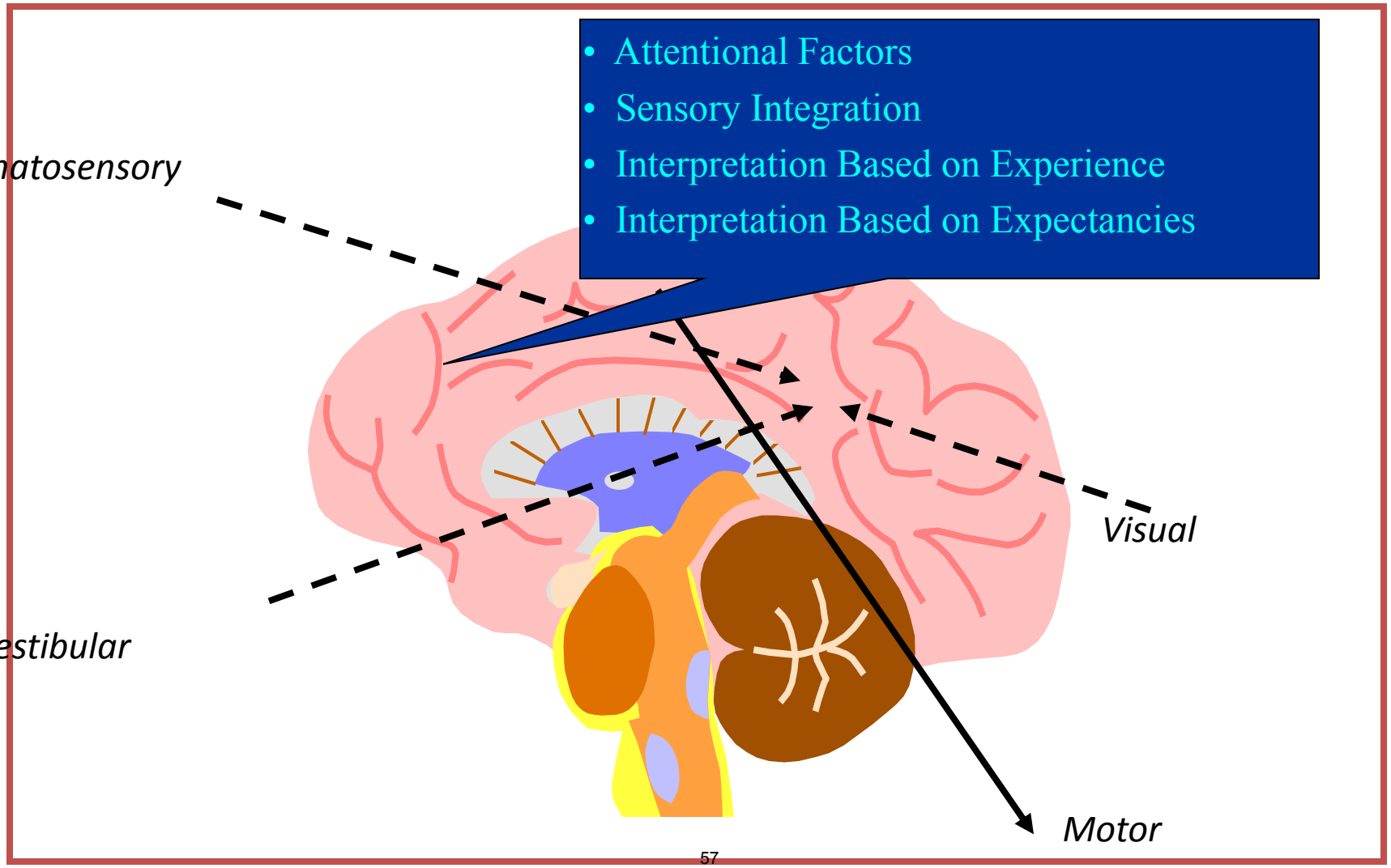


Image by MIT OpenCourseWare.

SPATIAL ORIENTATION IN FLIGHT
Cognitive Factors



SUMMARY

- Spatial orientation relies on three major sensory systems
- Ambient vision, along with the vestibular system, determines the spatial orientation frame-of-reference
- Focal vision is not optimal for maintaining spatial orientation; too attention-demanding
- The vestibular system is not well-suited to detecting sustained accelerations and rotations
- Control of spatial orientation is not normally under voluntary cortical motor control
- Spatial orientation is ultimately a cognitive construct

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Fall 2011